

Bathymetric Digital Elevation Model of British Columbia, Canada: Procedures, Data Sources, and Analysis

Prepared for NOAA, Pacific Marine Environmental Laboratory (PMEL) by the NOAA National Geophysical Data Center (NGDC)
July 24, 2013

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Summary

In July of 2013, NOAA's National Geophysical Data Center (NGDC) developed a bathymetric digital elevation model (DEM) of British Columbia, Canada for NOAA's West Coast and Alaska Tsunami Warning Center (WC/ATWC) and Pacific Marine Environmental Laboratory (PMEL). The 3 arc-second DEM will be used to support improving the coastal tsunami inundation forecasts. This DEM covers the coastal area offshore British Columbia. The extents of this DEM, procedures, data sources, and analysis are described below.

DEM Specifications

The British Columbia bathymetric DEM was built to the specifications listed in Table 1. Figure 1 shows the 3 arc-second DEM boundary in red.

Table 1. Specifications for the British Columbia, Canada DEM.

Grid Area	British Columbia, Canada
Coverage Area	122.20° to 137.45° W, 48.50° to 54.20° N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Sea Level (MSL)
Vertical Units	Meters
Cell Size	3 arc-seconds
Grid Format	ASCII raster grid

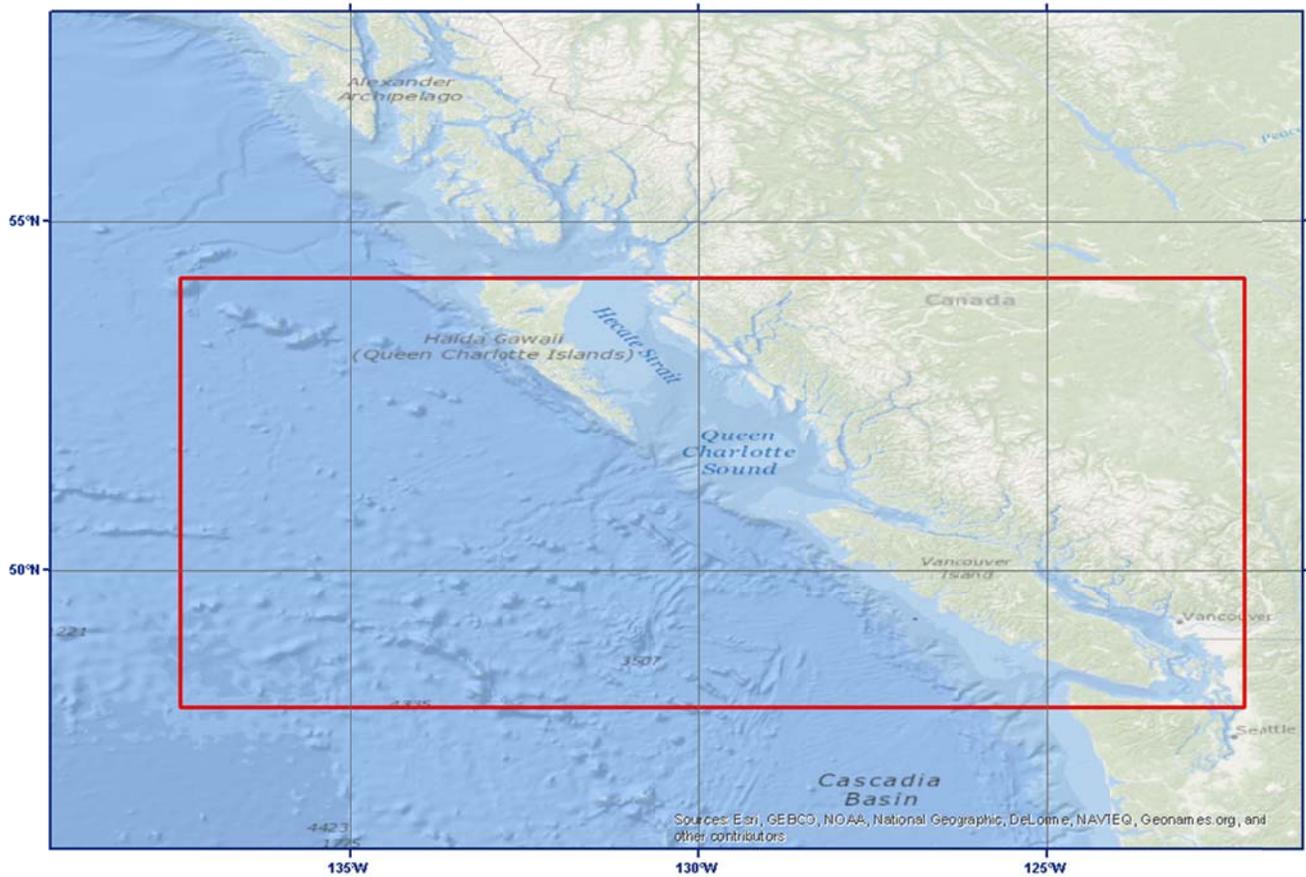


Figure 1. Map image of the DEM boundary for the British Columbia DEM in red.

Data Sources and Processing

The digital coastline used in developing the British Columbia DEM was generated by merging vector coastlines from NOAA Electronic Navigational Charts (ENCs) and Natural Resources Canada (NRCAN) then edited based on *ESRI* world imagery layer. The final digital coastline was converted to xyz format with elevation set at zero and point spacing at 10 meters. The digital coastline was also converted to a polygon and ultimately a raster for masking topography and eliminating interpolated data.

Bathymetry data used in the compilation of the British Columbia DEM included data from NOAA agencies, the Canadian Hydrographic Service (CHS), and compiled datasets from NGDC, USGS, and the British Columbia Marine Conservation Analysis (Figure 2 and Tables 2-4).

Table 2: Bathymetric data sources used in compiling the British Columbia DEM.

Source	Date	Data Type	Spatial Resolution	Horizontal Datum	Vertical Datum
NOAA NOS	1930 to 2011	Hydrographic survey soundings	1 meter to several kilometers	NAD 1927 or NAD 1983 UTM 10 North	Mean Lower Low Water (MLLW)
NOAA OCS	2012	Extracted chart soundings	1:30,000 to 1:1,200,000	WGS 1984 geographic	MLLW
NGDC	2002 to 2010	Multibeam swath sonar	Gridded to 3 arc-second	NAD 1983 geographic	Assumed Mean Sea Level (MSL)
Canadian Hydrographic Service (CHS)	1996 to 2012	Multibeam swath sonar	1 meter to 3 arc-seconds	WGS 1984 UTM 10 North	Lower Low Water Large Tide (LLWLT)
USGS	1999	Cascadia integrated bathymetric-topographic DEM	250 meters	Lambert Conformal Conic based on Clark 1866 ellipsoid*	Marine depths relative to MLLW
British Columbia Marine Conservation Analysis (BCMCA)	2012	Bathymetric DEM	100 meters	NAD 1983 Albers	Assumed Mean Sea Level
NGDC	2008	ETOPO1 Global DEM	1 arc-minute	WGS 1984 geographic	MSL
NGDC	2011	Port Townsend integrated bathymetric-topographic DEM	10 meters	WGS 1984 geographic	NAVD 88
NGA	1999-2011	Extracted chart soundings	1:141,935 to 1:250,000	WGS 1984 geographic	Lowest Normal Tide (LNT) or MLLW

* Custom projection

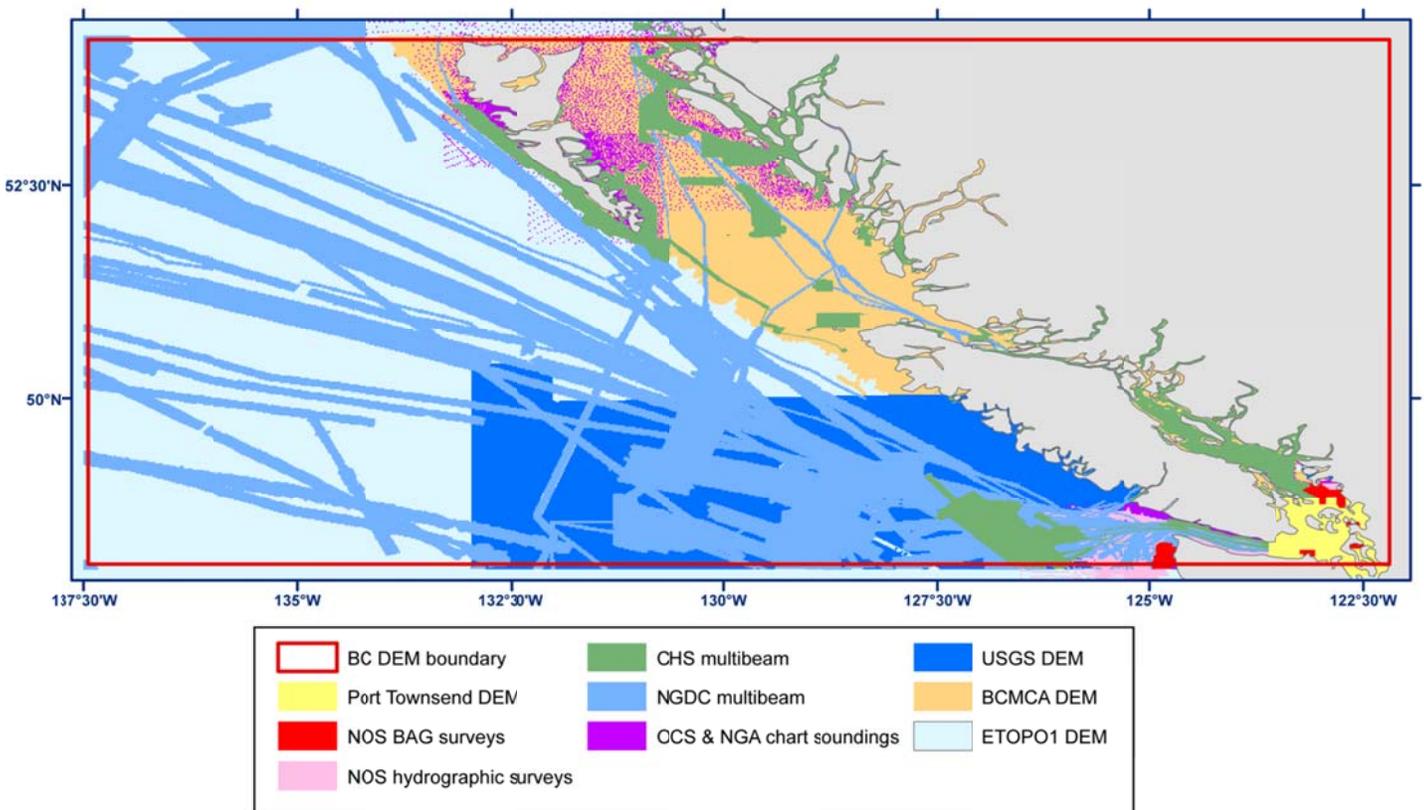


Figure 2. Source and coverage of datasets used to compile the British Columbia DEM.

Table 3: NOS hydrographic surveys

<i>Survey ID</i>	<i>Date</i>	<i>Original Horizontal Datum</i>	<i>Original Vertical Datum</i>	<i>Scale</i>
H05114*	1930	NAD 1927	MLLW	1:120,000
H05148*	1931	NAD 1927	MLLW	1:40,000
H05149*	1931	NAD 1927	MLLW	1:40,000
H05156*	1931	NAD 1927	MLLW	1:40,000
H05157*	1931	NAD 1927	MLLW	1:40,000
H05158*	1931	NAD 1927	MLLW	1:20,000
H05159*	1931	NAD 1927	MLLW	1:40,000
H05172*	1931	NAD 1927	MLLW	1:120,000
H06557*	1940	NAD 1927	MLLW	1:10,000
H08478*	1959	NAD 1927	MLLW	1:30,000
H08479*	1959	NAD 1927	MLLW	1:10,000
H08480*	1959	NAD 1927	MLLW	1:10,000
H08518*	1960	NAD 1927	MLLW	1:10,000
H08909*	1966	NAD 1927	MLLW	1:10,000
H09413*	1974	NAD 1927	MLLW	1:80,000
H09414*	1974	NAD 1927	MLLW	1:40,000
H09415*	1974	NAD 1927	MLLW	1:40,000
H09416*	1974	NAD 1927	MLLW	1:40,000
H11749	2007	NAD 1983 UTM 10 N	MLLW	10 meter
H11801	2009	NAD 1983 UTM 10 N	MLLW	1, 2, 5 meter
H12159	2010	NAD 1983 UTM 10 N	MLLW	4 meter
H12219	2010	NAD 1983 UTM 10 N	MLLW	2 meter
H12220	2010	NAD 1983 UTM 10 N	MLLW	8 meter
H12221	2010	NAD 1983 UTM 10 N	MLLW	4 meter
H12222	2010	NAD 1983 UTM 10 N	MLLW	8 meter
H12223	2010	NAD 1983 UTM 10 N	MLLW	8 meter
H12322	2011	NAD 1983 UTM 10 N	MLLW	8 meter
H12323	2011	NAD 1983 UTM 10 N	MLLW	16 meter
H12368	2011	NAD 1983 UTM 10 N	MLLW	16 meter
H12369	2011	NAD 1983 UTM 10 N	MLLW	8 meter

* indicates survey was used in development of final grid only, not bathymetric surface

Table 4: NGDC Multibeam swath sonar surveys

<i>Survey ID</i>	<i>Date</i>	<i>Ship</i>	<i>Source</i>
AII8L22	1987	Atlantis II	University of Rhode Island (URI)
AII8L41	1988	Atlantis II	University of Rhode Island (URI)
AT03L36	1999	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT03L37	1999	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT07L15	2002	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT07L16	2002	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT11L14	2004	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT11L15	2004	Atlantis	Woods Hole Oceanographic Institution (WHOI)

<i>Survey ID</i>	<i>Date</i>	<i>Ship</i>	<i>Source</i>
AT11L30	2005	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT11L31	2005	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT11L32	2005	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT18-09	2011	Atlantis	UNOLS R2R
AT3L23	1998	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT3L53	2000	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AT3L56	2000	Atlantis	Woods Hole Oceanographic Institution (WHOI)
AVON09MV	1999	Melville	University of California, Scripps Institution of Oceanography (UC/SIO)
DI9202	1992	Discoverer	National Oceanic and Atmospheric Administration (NOAA)
DI-95-03	1995	Discoverer	National Oceanic and Atmospheric Administration (NOAA)
EW0206	2002	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EW0207	2002	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EW0408	2004	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EW0409	2004	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EW9413	1994	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EW9505	1995	Maurice Ewing	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
EX0801	2008	Okeanos Explorer	National Oceanic and Atmospheric Administration (NOAA)
EX0802	2008	Okeanos Explorer	National Oceanic and Atmospheric Administration (NOAA)
EX0901	2009	Okeanos Explorer	National Oceanic and Atmospheric Administration (NOAA)
H10996	2000	Rainier	National Oceanic and Atmospheric Administration (NOAA)
H10999	2000	Rainier	National Oceanic and Atmospheric Administration (NOAA)
H11083	2003	Rainier	National Oceanic and Atmospheric Administration (NOAA)
H11086	2001	Rainier	National Oceanic and Atmospheric Administration (NOAA)
HEALY02	2001	Healy	Woods Hole Oceanographic Institution (WHOI)
HLY0101	2001	Healy	Rolling Deck to Repository (R2R) Program
HLY0201	2002	Healy	Rolling Deck to Repository (R2R) Program
HLY0401	2004	Healy	Rolling Deck to Repository (R2R) Program
HLY05TC	2005	Healy	Rolling Deck to Repository (R2R) Program
HLY06TA	2005	Healy	Rolling Deck to Repository (R2R) Program
HLY06TB	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY06TD	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY06TE	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY06TG	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY06TI	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY06TJ	2006	Healy	Rolling Deck to Repository (R2R) Program
HLY07TA	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY07TB	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY07TC	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY07TD	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY07TG	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY07TI	2007	Healy	Rolling Deck to Repository (R2R) Program
HLY08TA	2008	Healy	Rolling Deck to Repository (R2R) Program
HLY08TC	2008	Healy	Rolling Deck to Repository (R2R) Program
HLY08TG	2008	Healy	Rolling Deck to Repository (R2R) Program
HLY08TI	2008	Healy	Rolling Deck to Repository (R2R) Program
HLY09TA	2009	Healy	Rolling Deck to Repository (R2R) Program
HLY09TB	2009	Healy	Rolling Deck to Repository (R2R) Program

<i>Survey ID</i>	<i>Date</i>	<i>Ship</i>	<i>Source</i>
HLY09TC	2009	Healy	Rolling Deck to Repository (R2R) Program
HLY09TD	2009	Healy	Rolling Deck to Repository (R2R) Program
HLY09TE	2009	Healy	Rolling Deck to Repository (R2R) Program
HLY10TA	2010	Healy	Rolling Deck to Repository (R2R) Program
HLY10TB	2010	Healy	Rolling Deck to Repository (R2R) Program
HLY10TE	2010	Healy	Rolling Deck to Repository (R2R) Program
HLY11TA	2011	Healy	UNOLS R2R
HLY11TB	2011	Healy	UNOLS R2R
HLY12TA	2012	Healy	UNOLS R2R
HLY12TB	2012	Healy	UNOLS R2R
KM0514	2005	Kilo Moana	University of New Hampshire, Center for Coastal and Ocean Mapping (UNH/CCOM)
MGL0814	2008	Marcus G. Langseth	UNOLS R2R
MGL0909	2009	Marcus G. Langseth	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
MGL0910	2009	Marcus G. Langseth	UNOLS R2R
MGL1108	2011	Marcus G. Langseth	Rolling Deck to Repository (R2R) Program
MGL1211	2012	Marcus G. Langseth	UNOLS R2R
MGL1216	2012	Marcus G. Langseth	UNOLS R2R
OPRS9302	1993	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
RB0002	2000	Ronald Brown	National Oceanic and Atmospheric Administration (NOAA)
REM-01MV	1993	Melville	University of California, Scripps Institution of Oceanography (UC/SIO)
RITS93C	1993	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
RP14SU84	1984	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
RP15SU83	1983	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
SO108	1996	Sonne	University of Kiel, Germany, GEOMAR Forschungszentrum (GEOMAR)
SU-94-06	1994	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
SU-95-02	1995	Surveyor	National Oceanic and Atmospheric Administration (NOAA)
TN144	2002	Thomas G. Thompson	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
TN146	2002	Thomas G. Thompson	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
TN149	2002	Thomas G. Thompson	National Oceanic and Atmospheric Administration (NOAA/PMEL)
TN157	2003	Thomas G. Thompson	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
TN172	2004	Thomas G. Thompson	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
TN183	2005	Thomas G. Thompson	Columbia University, Lamont-Doherty Earth Observatory (CU/LDEO)
TN199	2006	Thomas G. Thompson	National Oceanic and Atmospheric Administration (NOAA/PMEL)
TN240	2009	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN243	2009	Thomas G. Thompson	UNOLS R2R
TN244	2009	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN247	2010	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN254	2010	Thomas G. Thompson	UNOLS R2R
TN255	2010	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN256	2010	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN264	2011	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN265	2011	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN266	2011	Thomas G. Thompson	UNOLS R2R
TN267	2011	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN268	2011	Thomas G. Thompson	UNOLS R2R
TN269	2011	Thomas G. Thompson	UNOLS R2R

<i>Survey ID</i>	<i>Date</i>	<i>Ship</i>	<i>Source</i>
TN270	2011	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program
TN279	2012	Thomas G. Thompson	UNOLS R2R
TN281	2012	Thomas G. Thompson	UNOLS R2R
TN282	2012	Thomas G. Thompson	UNOLS R2R
TN283	2012	Thomas G. Thompson	Rolling Deck to Repository (R2R) Program

NOAA NOS hydrographic survey data and BAG (Bathymetric Attributed Grid) data were downloaded from NGDC. Nautical chart sounding data were extracted from NOAA’s Office of Coast Survey (OCS) ENC Direct to GIS online extraction service (http://nauticalcharts.noaa.gov/csdl/ctp/encdirect_new.htm) and NGA’s Digital Nautical Chart service (<http://msi.nga.mil/NGAPortal/DNC.portal>). In deeper water, NGDC downloaded and gridded at 3 arc-second multibeam swath sonar data from NGDC’s multibeam database (Table 4). CHS multibeam data that was previously acquired for use in developing the Port Townsend DEM was gridded at 3 arc-seconds while the most recent data delivered to NGDC was converted to xyz format from the proprietary *CARIS* format and left at original resolution. Extracted sections of existing digital elevation models, ETOPO 1, BCMCA, and USGS Cascadia DEMs, were used in the areas where no multibeam or hydrographic survey data were available. By generating a mask of higher resolution data, the DEM data were clipped where better data exists.

These bathymetric data were transformed to WGS 84 and retained their original vertical datum of mean lower low water (MLLW), Lower Low Water Large Tide (LLWLT), or mean sea level (MSL) prior to DEM development. Source elevation data were not converted to a common vertical datum due to the large cell size of the DEM (3 arc-second; ~90 meters). This means that the vertical uncertainty of the DEM elevations for a grid cell exceeds the differences between vertical datums (less than 3 meters).

DEM Development

After the data were transformed to common horizontal datums, the data were reviewed for consistency and errors using *ESRI ArcMap* and *Applied Imagery QT Modeler*. Where more recent, higher resolution data existed, older data were superseded. In some areas, older multibeam data were retained as newer overlapping data contained errors during data acquisition. The edited and evaluated data were then converted to ASCII xyz format using either *ArcCatalog* tools and *GDAL* then gridded at 3 arc-second using *GMT*’s ‘surface’ tool to generate a bathymetric pre-surface which provided full data coverage of the DEM area for use in the final gridding process. The surface was converted to xyz format using *GDAL* and along with the NOS BAG survey data, all multibeam data, the Port Townsend DEM, and the coastline xyz data were gridded using *MB-System* tool ‘mbgrid’. This tool applies a tight spline tension to the data using the designated data hierarchy gridding weight (Table 5). The gridding process was done in two tiles which were both clipped to the coastline mask using *ArcCatalog* grid math tools and mosaicked together.

Table 5: Data hierarchy used to assign gridding weight in MB-System.

<i>Dataset</i>	<i>Relative Gridding Weight</i>
NGDC Port Townsend DEM	100
CHS multibeam 2011-2012	100
NOS BAG surveys	100
NGDC multibeam	10
CHS multibeam 1996 - 2010	10
Bathymetric pre-surface	10
Coastline	1

DEM Analysis

Once the British Columbia DEM was generated, the grid was compared to nautical chart contour data and a random selection of source data. Inconsistencies and gridding artifacts were evaluated and resolved based on most reliable data available.

Recommendations to improve the British Columbia 3 arc-second DEM are listed below:

- Integrate near shore hydrographic survey data for coastal areas in the DEM.
- Conduct deep-water multibeam surveys to replace global datasets.

Acknowledgement

The authors thank Peter Wills and Denny Sinnott of the Canadian Hydrographic Service for providing data used in developing the British Columbia DEM.

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